Cooling and Heating in the Cement Grinding Process

Hp. Fisch
PT 99/14489/E

1. INTRODUCTION

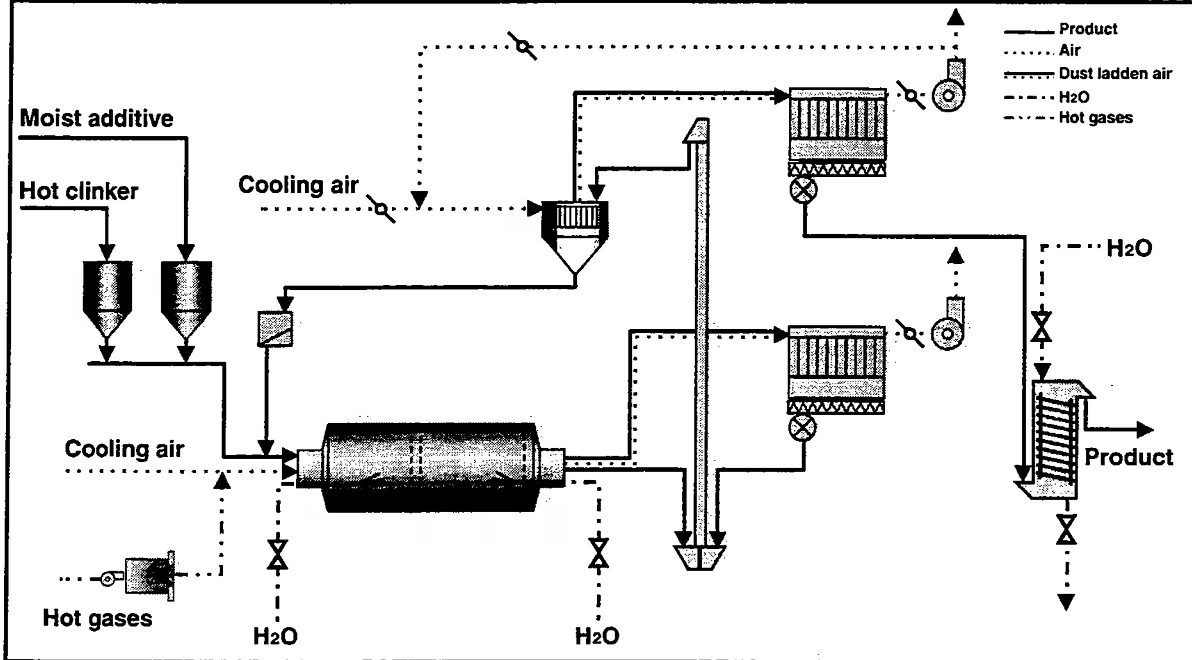
Cooling and heating in the cement grinding process becomes more and more important. On one hand the market demands in many areas cool cement (e.g. < 60 °C) and on the other hand the cement manufacturing process requires an accurate balancing of the material temperature. The grinding process does not only require cooling but also heating is necessary in many cases to keep the process optimal and to assure a determined cement quality. Specially with the increasing production of blended cements with moist additives, the temperature must be neatly monitored and assured to efficiently produce a good quality product.

The following paper deals with cooling and heating of tube mill systems. Some considerations are also valid in an adapted way to other mill principles such as roller presses, vertical and horizontal roller mills.

What refers to drying and heat balances for various materials is dealt with in the paper "Drying Technology PT 96/14027/E". The heat balance at the end of this paper is adapted for a cement grinding system.

2. COOLING AND HEATING POSSIBILITIES

Fig.1 Cooling / heating possibilities



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There are and were many possibilities for cooling and heating in the cement grinding process. The main possibilities are:

Cooling

- Air cooling of the mill (mill ventilation), where the air has a combined function of cooling and to some extent material transport through the mill.
- Air cooling in the separator by using an adjustable amount of ambient air to cool the mill discharge product which will be divided into finish product and separator returns.
- Water spray into the mill, depending on the conditions into the 1^{st} and/or the 2^{nd} compartment, to keep the mill discharge temperature within limits.
- Cement cooling with a cement cooler. The cement slides over a water cooled cylindrical surface and is cooled by convection.

Heating

- Hot gases/air can be used to evaporate the moisture in the mill feed and to keep the temperature profile within the mill above determined levels. Hot gas may be supplied by hot gas generators or kiln exhaust gases as well as clinker cooler exhaust air used.

3. MILL VENTILATION AND DEDUSTING

3.1 Mill air cooling

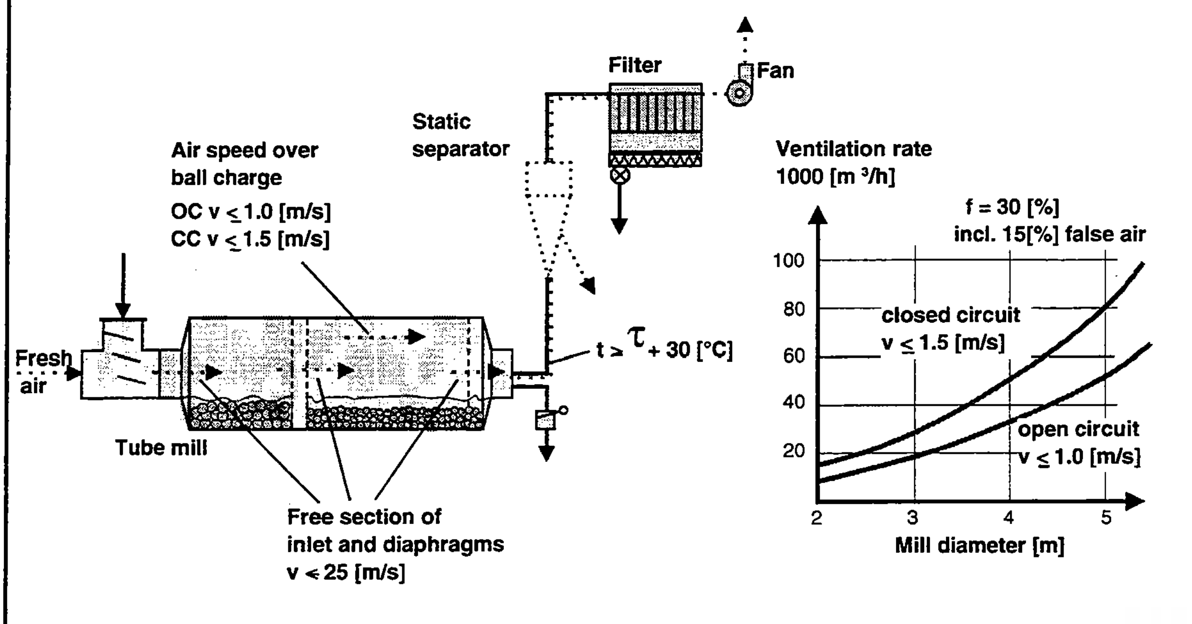
Purpose

The mill ventilation has 3 main functions

- mill (product) cooling
- transport of fines through mill
- fluidization of material within the mill

System

Fig.2 Mill ventilation



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The mill inlet has to provide sufficient open area to draw in the ventilation air. Preferably stair type inlets are used.

Diaphragms and mill outlets should be designed to enable an adequate passage of air at reasonable air speeds to keep the air pressure low.

The mill outlet seal has to minimize the false air inleakage and therefore a pendular flap must be installed.

The static separator is still used in older mill systems. For new installations the static separator is no more used as the new dynamic separators are more efficient.

Dimensioning of mill ventilation

♦ Air flow rate

  The installed air flow rate is only based on the air speed over the ball charge. Fig 2 shows the values based on nominal mill diameters, 30 [%] ball filling and 15 [%] false air. The air flow rates are therefore nominal fan volumes.

  Air speeds for system dimensioning are:

  - closed circuit mills $\leq$ 1.5 [m/s] over ball charge
  - open circuit mills $\leq$ 1.0 [m/s] over ball charge

♦ Inlet, outlet and diaphragms, maximum air speeds of $\leq$ 25 [m/s] related to gross open area.

♦ A false air rate of ~15 [%] has to be considered between mill outlet and fan. This results normally in air temperature of 5 [°C] below cement temperature at mill discharge. Higher temperature differences point to higher false air rates.

♦ The mill exhaust air temperature must always be kept $\geq$ 30 [°C] above the dew point temperature (τ) to avoid condensation problems. Excessive false air favors condensation.

3.2 Mill heating for blended cements

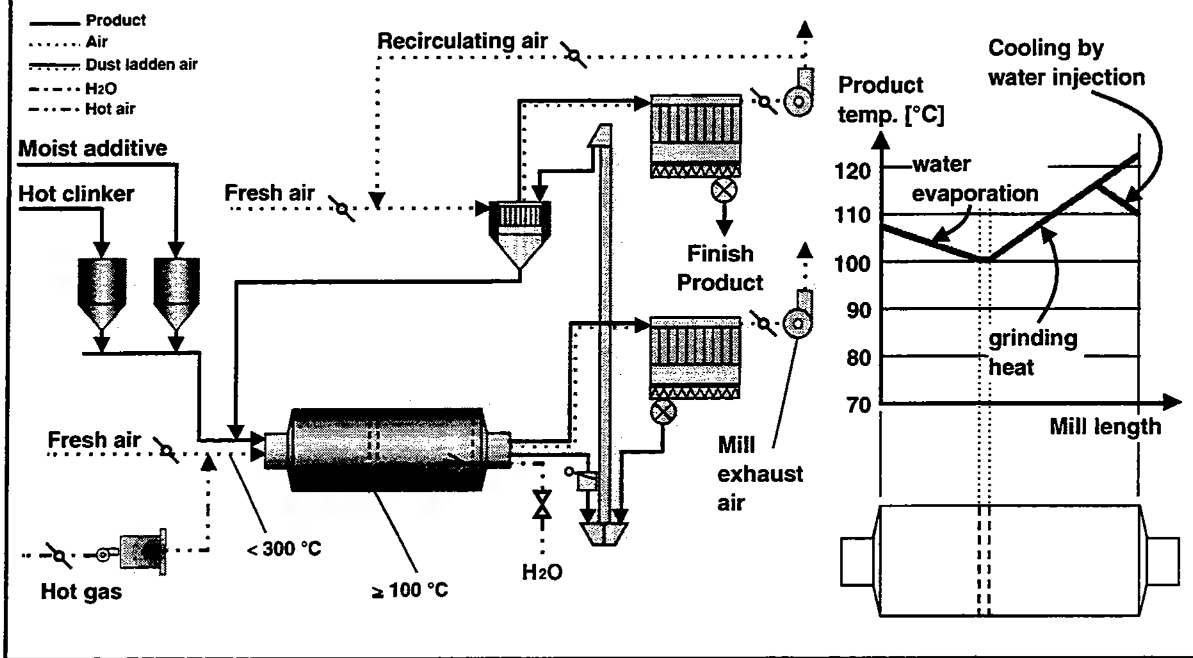
In many cases, specially when grinding blended cements with moist additives, heating is required instead of cooling.

Up to a certain moisture content in the feed, clinker and grinding heat are sufficient to evaporate the moisture. However often additional heat is required for drying. This heat can be taken from kiln exhaust gases, clinker cooler exhaust air or be generated by an auxiliary furnace (hot gas generator).

As a general rule it can be said, that the material fed to the mill must be dry at the intermediate diaphragm. If not, severe operating problems may arrive e.g. clogging of diaphragm, bad material flow behaviour etc.

The experience has shown, that material temperature below ~100 [°C] at the intermediate diaphragm reduces the grinding efficiency and the mill production (due to moist material and poor material flow). With such conditions, due to grinding heat of the 2nd compartment, the mill discharge temperature increases and must be cooled down again by water injection in the mill outlet to reach the appropriate product temperature at the mill discharge.

Fig.3 Mill heating for blended cements



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In cases of drying needs, all separating air in the separator must be recirculated to keep the maximum temperature of the separator grits returning to the mill inlet and keep the maximum heat within the mill system.

For blended cements with lower moisture contents, drying can take place directly in the first grinding compartment. With higher moisture contents a drying compartment is necessary or the additives must be dried before feeding to the mill. The limit for drying in the grinding compartment is approx. 4 [%] mixed moisture in the mill feed, but depending on the clinker temperature and clinker proportion in the mix, as well as the available hot gas temperature.

The mill inlet temperature with hot gases should not exceed 300 [°C], as above this temperature adverse effects on gypsum dehydration will take place.

Special attention should be paid to dimensioning of the hot gas generator. Many times hot gas generators are sized for the maximum drying needs plus reserve. In these cases the turn down ratio must be such, that also minor moisture contents can correctly be dried with a good and stable operation of the furnace.

Bag filters for dedusting of the mill system must be insulated and cold spots avoided to eliminate the risk of condensation.

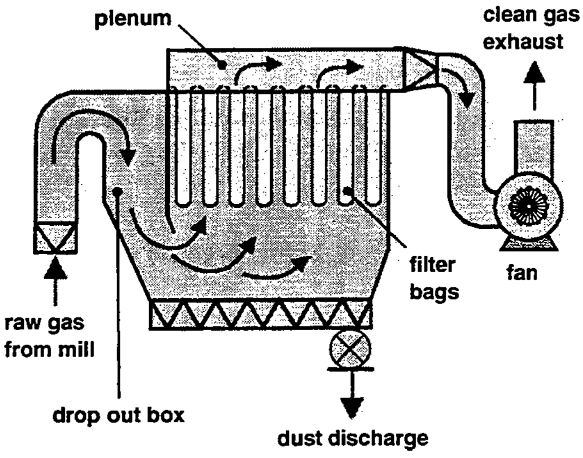
4. FILTER TECHNOLOGY

For dedusting of mills and separators only bag filters are used today, regardless of the fact that ordinary portland or blended cements are produced. Electrostatic precipitators are no more applied due to operational and environmental reasons.

The mill bag filter should only be used for mill ventilation and not additionally dedust other equipment. Also mill dedusting air drawn through the dynamic separator must be avoided due to operational difficulties.

Filter sizing

Fig.4 Filter technology



raw gas dust content 300 - 800 [g/m3]
clean gas dust content ≤ 25 [mg/m3]
Δp filter = 5 - 14 [mbar]

Filter sizing

Air cloth ratio

80 [m3/m2 x h] without grinding aid
60 [m3/m2 x h] with grinding aid

Bag dimensions

bag Ø 140 - 160 [mm]
bag lengths ≤4.5 [m]

Filter cloth

- needle felt/polyester - general purpose
- Dolomite PEAC - mixed needle felt
- new products (e.g.teflon treated fibres)

} - drying/grinding applications

Compressed air

≥ 0.13 - 0.19 [m3/h x m2]

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A properly sized and well engineered filter avoids a lot of operating problems and saves costs.

Filter design

There are many different types, makes and philosophies to design and install bag filters. Preferred filters are pulse jet types. It is important to install a properly sized filter with sufficient compressed air. The compressed air must have decent air dryers, specially in tropic countries to avoid contact of moist air with cement and hence clogging of the bags.

In case of higher dew points and installations outside of buildings an insulation of the filter is necessary.

A dust drop-out box can be installed at raw gas dust contents > 300 [g/m^3], however not all suppliers favor such installations.

Walk-in plenums present advantages with regard to tight housings (less false air) and can be installed outdoors without problems.

Filter operation

Special attention should be paid to the shut down procedure:

- Continue cleaning the filter bags for a couple of cleaning cycles before allowing the temperature to drop below the dew point. As the filter cools, moisture may condense on the bags once the dew point is reached.
- Do not store dust in the hopper. The presence of any moisture will cause it to set, requiring manual work for its removal.
- Allow bags to clean down after dust has stopped entering the hopper, but do not over clean.
- Check to see that all components are in the proper shut down mode.

5. WATER INJECTION

Purpose

Tube mills generate a lot of heat and together with hot clinker increase the product /temperature along the mill axis. Too high material temperatures in the mill may cause

- coating (hampering fluidization of material)
- false set of cement (by dehydration of gypsum to soluble anhydrite and then recrystallization to gypsum)
- cement storage problems in silo (lump formation).

If the cooling by fresh air and radiation/convection is not sufficient, water injection into the mill is necessary. The aim of water injection is to evaporate water and so to extract heat from the material.

Water injection systems

Fig.5 Water injection - systems

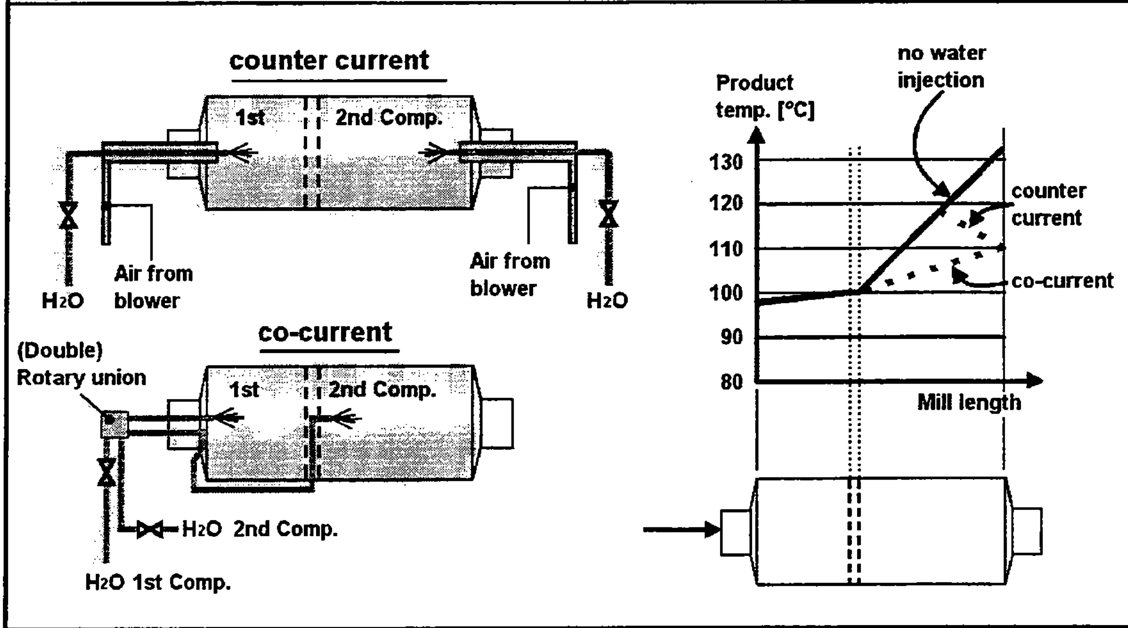

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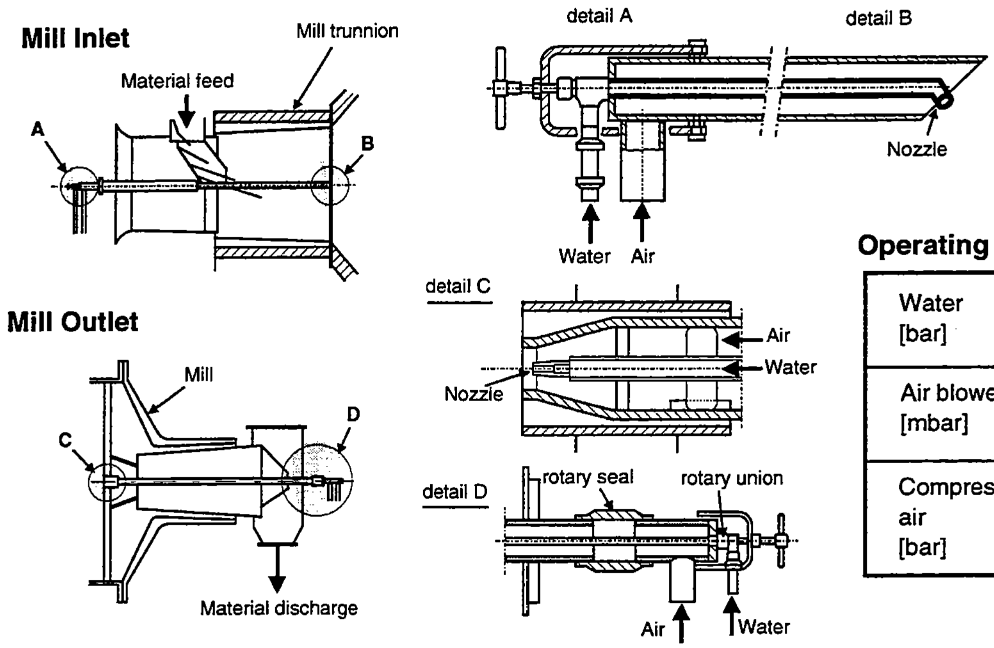
Fig.6 Water injection - devices



Operating Pressures

Water [bar]	min normal max	3 4-6 9
Air blower [mbar]		≥ 50
Compressed air [bar]		~5

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Water can be injected into the

- 1st compartment
- 2nd compartment
  - from inlet (co-current)
  - from outlet (counter-current)

The co-current injection into the 2nd compartment requires an installation of the water pipe from the center of the inlet around the shell of the first compartment to the center of the intermediate diaphragm. The installation is more complex but the cooling effect is more favorable, as the temperature increase is slight and the temperature level is lower than for counter-current installations (graph. of Fig. 5). The injection should be in form of a spray rather than a jet to keep the evaporation in the first part of the compartment.

Counter-current injections are easy installations (except with central drives) and cool down rapidly the last part of the compartment. In general, the temperature level over the second compartment is higher than with co-current injections. The injection should be a jet reaching far into the grinding compartment.

Counter-current systems are easy to install in mills with pinion or side drives. With central drives, injection glands around the central drive shaft have to be fitted. Many poor experiences with the tightness of these glands have been made and therefore it is not recommended to adopt such solutions.

If ever possible the water spray nozzles should be surrounded by tubes, carrying air from a blower to keep the nozzle always clean (Fig. 6). Leading compressed air together to the water pipe and to the spray nozzle is an other solution.

Operation

Every time the cement mill is running or the mill ventilation is on, the cleaning air of the water injection system must be running. After a mill stop, the air cleaning system must continue for a few minutes.

Water is in general first injected into the second compartment and only when the cement temperature at the mill discharge exceeds 100 [°C]. Injection into the first compartment is only allowed when feeding hot clinker (mixed temperature $\geq$ 100 [°C]). Below these temperatures there is a risk of not sufficient evaporation of the water and clogging of diaphragms.

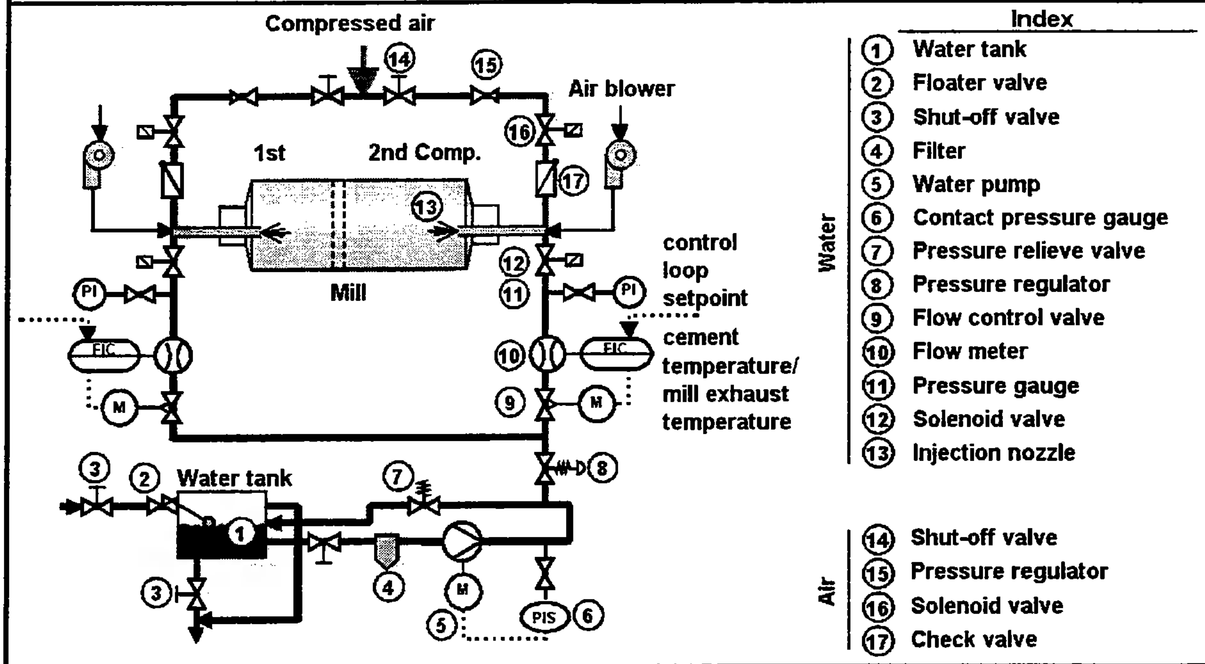
Water injection acts like grinding aid in the mill and fluidizes the material. The control of water injection should therefore always gradually be changed (no steps) to avoid rapid emptying or filling of the mill.

When no water is injected the solenoid valves must be closed and tight to avoid water from dripping into the mill.

In most cases the max. portion of water injected into the first and second compartment is done according to their percentage in length e.g. max 1/3 into the first and 2/3 into the second compartment.

Control

Fig.7 Water injection - control



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The water injection is controlled with a control loop in function of the clinker or cement temperature.

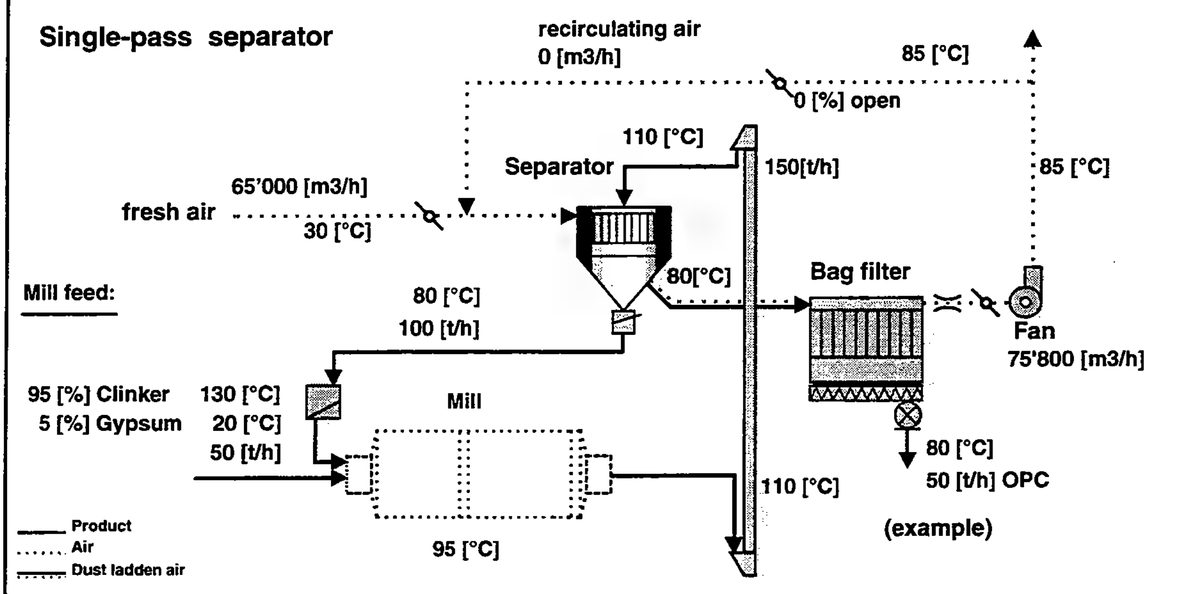
In the first compartment either the clinker temperature of the mill feed or the cement temperature at the intermediate diaphragm are the process values measured.

In the second compartment either the cement (mill discharge) or the exhaust gas/air temperature can be taken. The exhaust air temperature is normally min. 5 [°C] below the cement temperature, depending on the false air rate.

The control loop consists of a water flow meter which value is compared to the set point of the controller (based on measured temperature). Any change is transmitted the water flow control valve for a corresponding adjustment.

6. COOLING IN THE SEPARATOR

Fig.8 Cooling in the separator



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Cooling of the cement, finish product and separator grits, can be done in the separator, in case the separator system allows for.

New separators can be fitted with bag filters as single pass separators. The air passes through the separator, filter and fan. The clean fan exhaust air can be blown to the atmosphere or recirculated to the separator inlet. Fresh air substitutes the exhausted air and does the cooling in the separator. The more fresh air with ambient temperature is used the higher is the cooling effect. The more air is recirculated the lower the cooling.

At least 5 [%] of the total separating air is always fresh air in form of false air inleakage. The cooling level is adjusted by the recirculating and the fresh air flap.

A cold mill should always be started up with a maximum amount of recirculating air to heat up the mill system. As soon as the operating temperatures of the mill system are reached then fresh air can be used to cool down the material to the target temperatures.

A maximum cement cooling capacity of a separator, cooling with fresh air is around 25 – 30 [°C]. For higher cooling needs, additional cooling facilities e.g. cement coolers have to be used.

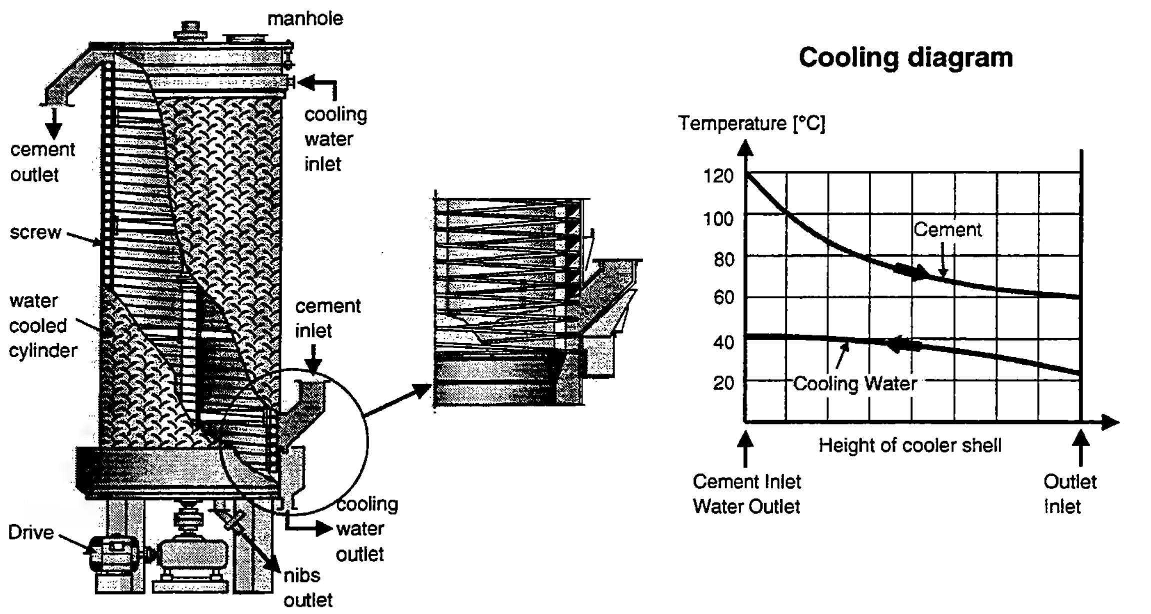
Besides cooling the finish cement to the silo, this cooling method also cools down the separator grits returning to the mill inlet. Cool separator grits have on one hand a cooling effect in the first mill compartment but can on the other hand cool down too much. At too low material temperatures at the intermediate mill diaphragm the mill production is reduced. In this case the temperature level of the separator grits must be increased again by recirculating more warm separating air back to the separator inlet.

In any case a detailed heat balance must be calculated to give the necessary information for the prevailing situation and the cooling/heating needs.

Fig. 8 shows a tube mill system with a singlepass separator. The example shows the cooling effect at maximum fresh air amount used at the separator inlet. As a result, the material temperature at the intermediate diaphragm is low and leads to reduced mill production rate.

7. CEMENT COOLERS

Fig.9 Cement coolers



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Purpose

Cylindrical cement coolers are efficient and low energy consuming solutions to cool down the cement after the grinding process. Reasons for cooling may be

- customer requirement
- cement bagging and bag handling at low temperature
- avoid lump formation in the cement silos (<70 [°C]: reduction of water release from gypsum dehydration)

Principle

Water cascades in a thin layer over a cylindrical body from the top to the bottom and cools down the cooler shell. Hot cement is introduced to a type of screw conveyor at the bottom and conveyed up along the cooler shell to the discharge at the top. Intense heat transfer occurs from the cement powder at the inside of the shell, through the shell wall to the water layer at the outside. The cooling occurs in counter current, that means the best cooling is done with the lower water temperature at the cement discharge at the top of the cylinder.

The cooling water recirculates in a closed water circuit. A water cooler reduces the water temperature before feeding it again to the top of the cylinder.

Performance

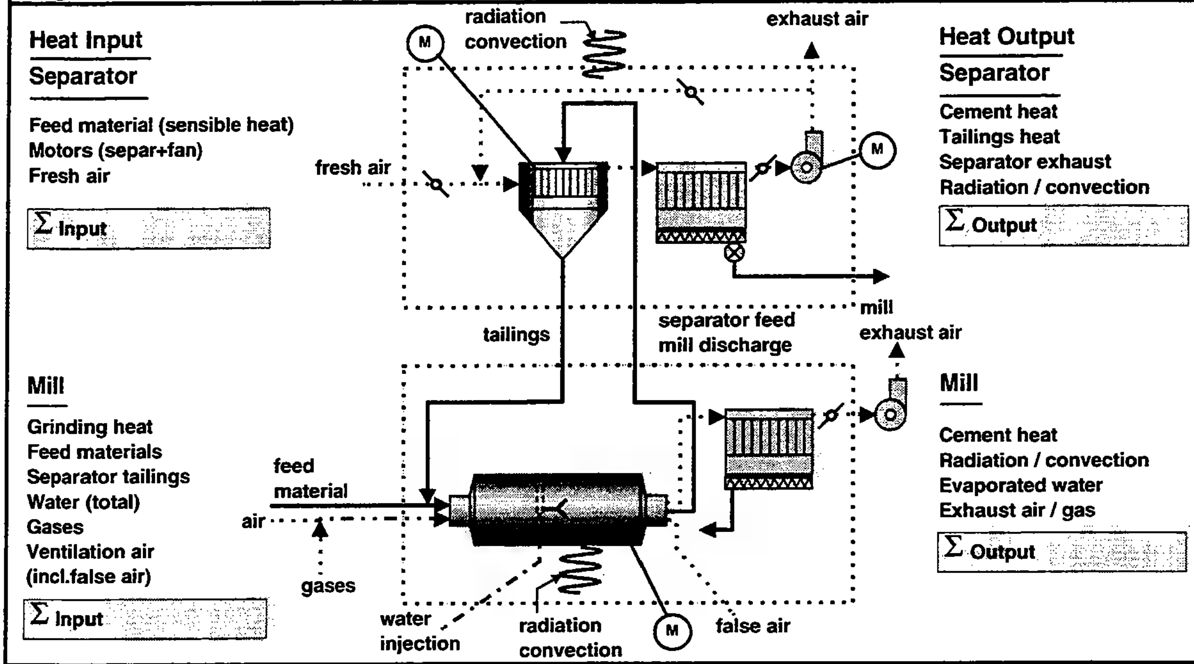
- Cement coolers exist up to 200 [t/h] for a single cylinder.
- The cylinder size varies with the cement throughput and the cooling capacity.
- Cooling the cement from 120 [°C] down to ~60 [°C] is common.
- The spec. cooling rate is approx. 1.25 [kJ/m °C h].
- Typically the cooing water is heated up from 25 – 40 [°C] along the cylinder.
- Spec. electrical energy consumption of cooler and water treatment plant is approx. 1 [kWh/t] cement.
- Increasing ovality of the cylindrical shell decreases the efficiency. A minimum clearance between screw flights and shell has to be aimed at.

Water treatment

- The water must have an acceptable quality, often the water must be softened by decalcifying units to avoid lime furring on the cooling surfaces.
- Lime furring can also be reduced through a cathodic protection of the shell.
- The water consumption in a closed water circuit refers only to the make-up water due to the losses in the water cooling units.

8. HEAT BALANCE (ENERGY BALANCE)

Fig.10 Heat balance - system



Cooling and Heating

If ever cooling or heating needs must be calculated, the appropriate model is a heat balance calculation. The aim of such a calculation is to check the temperatures at the critical points and the quantities of cooling air, water or hot gases needed to fulfil the requirements.

In principle all heat inputs (energy) have to be equal to the heat outputs of the system in question.

Heatbalance: Σ Inputs = Σ Outputs

Procedure

1) Define borders of the system(s); for cement grinding systems it is recommended to define two systems, separator and mill part.
2) Define inputs and outputs for each system.
3) Compute the balances based on

Heat	inputs	=	outputs	[kJ/kg product]
Air/gas flows	inputs	=	outputs	[Nm^3/h]

4) Observe the restrictions

- max. gas/air speeds in mill, mill inlet/outlet
- max. gas temperature at mill inlet (available and recommended)
- max. possible water injection rate for 1st and 2nd compartment

- plant altitude (density of air)

Hints

- The balance can be equally done for any grinding equipment (tube mill, vertical mill, roller press, horizontal mill etc.) based on the same principle and adapting the systems according to the features of the equipment.
- The heat is always related to 1 [kg] of finish cement at the system outlet.
- The heat balance is based on the reference temperature of 20 [°C], therefore the Δt is always (t-20) and negative heats are possible.
- All grinding heats of the major electrical consumers are referred to their motor shafts and have to be converted to the mechanical power absorbed of this equipment if necessary.
- The evaporation heat of water consists of heating up the water to the operating temperature an the subsequent portion of evaporation energy.
- The radiation/convection losses are often assumed and are related to an estimated surface (e.g. mill surface times factor x) at an estimated surface temperature (e.g. t-10 [°C]).

Heat balance example

Fig. 11 Heat Balance Cement Mill Example "HOLDERBANK"

Heat Balance Mill:							
Grinding heat	P_{abs} * η * 3.6 * 1000	/ G * 1000	5000 * 0.91 * 3.6 * 1000 / (180 * 1000)	91.0	[kJ/kg]	33.4	[%]
Separator tailings	G * (u-1)) * cp * (t-20) * 1000	/ G * 1000	180 * (2-1) * 0.819 * (104-20) / (180 * 1000)	68.8	[kJ/kg]	25.2	[%]
Feed material heat	G * cp * (t-20)	/ G * 1000	180 * 0.806 * (110-20) / (180 * 1000)	73.2	[kJ/kg]	26.9	[%]
Water (feed + injection)	W_{in} * 4.2 * (t-20)	/ G * 1000	5410 * 4.2 * (15-20) / (180 * 1000)	-0.7	[kJ/kg]	-0.2	[%]
Gases	V_G * cp * (t-20)	/ G * 1000	11'000 * 1.529 * (450-20) / (180 * 1000)	40.2	[kJ/kg]	14.8	[%]
Air (including false air)	V_a * cp * (t-20)	/ G * 1000	15'290 * 1.3 * (20-20) / (180 * 1000)	0.0	[kJ/kg]	0.0	[%]
INPUT:				**272.5**	**[kJ/kg]**	**100**	**[%]**
Cement heat ex mill	G * u * cp * (t-20) * 1000	/ G * 1000	180 * 2 * 0.822 * (110-20) / (180 * 1000)	148.0	[kJ/kg]	54.3	[%]
Radiation / convection	k * A * (t-20) * 3.6	/ G * 1000	14.15 * 1030 * (110-20) * 3.6 / (180 * 1000)	26.2	[kJ/kg]	9.6	[%]
Water (evaporated)	W_{ev} * q	/ G * 1000	5'410 * (2501 + (1.88 * 105)) / (180 * 1000)	81.1	[kJ/kg]	29.8	[%]
Exhaust air /gas	V_{ex} * cp * (t-20)	/ G * 1000	26'850 * 1.358 * (105-20) / (180 * 1000)	17.2	[kJ/kg]	6.3	[%]
OUTPUT:				**272.5**	**[kJ/kg]**	**100**	**[%]**

Heat Balance Separator:							
Separator Feed	G * u * cp * (t-20) * 1000	/ G * 1000	180 * 2 * 0.822 * (110-20) * 1000 / (180 * 1000)	148.0	[kJ/kg]	97.0	[%]
Motors separator + fan	P_{abs} * η * 3.6 * 1000	/ G * 1000	282 * 0.8 * 3.6 / (180 * 1000)	4.5	[kJ/kg]	3.0	[%]
Separating air (fresh)	V_s * 1.3 * (t-20)	/ G * 1000	3'032 * 1.3 * (20-20) / (180 * 1000)	0.0	[kJ/kg]	0.0	[%]
INPUT:				**152.5**	**[kJ/kg]**	**100**	**[%]**
Tailings	G * (u-1) * cp * (t-20) * 1000	/ G * 1000	180 * (2-1) * 0.819 * (104-20) / (180 * 1000)	68.8	[kJ/kg]	45.1	[%]
Radiation / convection	k * A * (t-20) * 3.6	/ G * 1000	14.15 * 550 * (104-20) * 3.6 / (180 * 1000)	13.1	[kJ/kg]	8.6	[%]
System exhaust air	V_{sex} * cp * (t-20)	/ G * 1000	3'032 * 1.3 * (104-20) / (180 * 1000)	1.8	[kJ/kg]	1.2	[%]
Cement heat	G * cp * (t-20) * 1000	/ G * 1000	180 * 0.819 * (104-20) / (180 * 1000)	68.8	[kJ/kg]	45.1	[%]
OUTPUT:				**152.5**	**[kJ/kg]**	**100**	**[%]**

Heat of evaporation $q = 2501 + (1.88 * t)$ [kJ/kg H_2O] heat of evaporation at exhaust temperature

Radiation / convection factor $k = ((\Delta t_{surf}-10) * 0.055) + 9.75$ [kJ/m² °C h]

Balance related to: 1 [kg] of cement

Reference temperature 20 [°C]

Cement grinding system

System:	Tube mill with separator				
	Mill diameter		4.6	[m]	
	Mill length		15.5	[m]	
	Motor power		5000	[kW] abs.	
[%]	Overall drive eff.		91	[%]	
Operating data:					
	Production		180	[t/h]	Pozzolana cement
	Composition	Clinker	71	[%]	gypsum
		Gypsum	4	[%]	4 [%] H_2O
		Pozzolana	25	[%]	8 [%] H_2O
	Clinker temperature		150	[°C]	
	Ambient temperature		20	[°C]	
	Water temperature		15	[°C]	
	Hot gas temperature		450	[°C]	
	Mill inlet temperature		~200	[°C]	
	Mill discharge temp. (cement)		110	[°C]	
	Mill discharge temp. (gas)		105	[°C]	
	Finish product temperature		104	[°C]	
	Mill fan flow rate		33000	[Nm^3/h]	

Index

G	[t/h]		mill production	
u	[-]		circulation factor (feed/product)	
t	[°C]		Temperature	
$P_{abs.}$	[kW]		absorbed power (counter)	
η	[-]		efficiency of drives	
cp	[kJ/kg]		spec. heat value (related to reference temperature)	
	[kJ/Nm^3]			
W	[l/h]		water to be evaporated	
		index:	in	moisture in feed material (incl. water injected)
			ev	evaporated water
V	[Nm^3/h]		air/gas flow rate	
		index:	g	gas
			a	fresh air
			ex	exhaust air
			s	fresh air separator
k	[kJ/m^2 °C h]		radiation/convection factor	
A	[m^2]		radiation surface	
q	[kJ/kg H_2O]		heat of evaporation	

The cp-values are given in Fig. 12.

For the additives pozzolana, fly ash and gypsum the cp-values of raw material can be used.

Fig. 12